It is probable that diffusion will be too small to be measured at temperatures where processes other than the simple six-jump process may be ignored. The more complicated processes which will come into play at slightly higher temperatures would not, however, be expected to change the ratio G very greatly. We may therefore reasonably expect that, at low temperatures, the two diffusion constants will lie within a factor of two or three of one another and this expectation is borne out by the experimental results.[4]

[1] L. Slifkin and C. T. Tomizuka, Phys. Rev. **97**, 836 (1955).
[2] A. B. Lidiard, Phys. Rev. **106**, 823 (1957).
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Effective Nuclear Spin Interactions in Ferromagnets

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(Received November 25, 1957)

THIS note is to draw attention to a type of nuclear spin-spin interaction which may be at the root of the difficulty of observing nuclear resonance of the metal nuclei in ferromagnetic and antiferromagnetic insulators.

The interaction takes place as follows: Each nuclear spin sees the electronic spin on its own ion, through the effective hyperfine coupling $A\mathbf{I}\cdot\mathbf{S}$. The electronic spins of all the ions are coupled by exchange interaction. An interaction of the nuclei therefore arises via the low-lying excited states (spin waves) of the electronic system as intermediate states.[1–4] That is to say, a nuclear spin excites a spin wave through the hyperfine coupling, and another nuclear spin causes it to be reabsorbed through its hyperfine coupling. For a cubic ferromagnet, summation of this process over all the possible virtual spin-wave states leads to a nuclear interaction of the form

$$\mathfrak{H}_{\mathrm{eff}}=-\frac{A^2S}{8\pi g\mu_BH_{\mathrm{ex}}}\sum_{i\neq i}\frac{a}{r_{ij}}\exp\left[-\left(\frac{H_{\mathrm{int}}}{H_{\mathrm{ex}}}\right)^{\frac{1}{2}}\frac{r_{ij}}{a}\right]I_i^-I_j^+, \tag{1}$$

where r_{ij} is the distance between sites i and j, a the lattice spacing, A the hyperfine coupling constant, S the ionic spin, H_{ex} an effective exchange field, H_{int} the effective dc field (i.e., the applied steady field minus the demagnetizing field). $I_i^\pm$ stands for $I_i^x\pm iI_i^y$, where I_i^x, I_i^y are the nuclear spin components in a plane normal to the quantization direction, which is taken to be the direction of H_{int}. Demagnetization effects (other than in H_{int}) were neglected, the energy of a spin wave quantum of wave number k being taken in the form $\hbar\omega_k=g\mu_B(H_{\mathrm{int}}+H_{\mathrm{ex}}a^2k^2)$. If demagnetization effects are included, interactions of the form $I_i^+I_j^+$ and $I_i^-I_j^-$ will also occur, leading to satellite lines. The self-energy term $i=j$, which has been omitted from (1), gives a small shift in the nuclear resonance frequency, and, if $I>\frac{1}{2}$, also a small quadrupole effect.

The interaction (1) will lead to a nearly Gaussian line profile,[5] with root-mean-square width given by Van Vleck's formula.[6] Since the range of the interaction is rather long (about 30 lattice spacings for $H_{\mathrm{ex}}\sim10^6$ oe and $H_{\mathrm{int}}\sim10^3$ oe), the sum in Van Vleck's formula[6] may be replaced by an integral, with the result

$$\langle(\Delta\nu^2)\rangle^{\frac{1}{2}}=S\left[\frac{I(I+1)}{24\pi}\right]^{\frac{1}{2}}\left(\frac{H_{\mathrm{ex}}}{H_{\mathrm{int}}}\right)^{\frac{1}{4}}\left(\frac{A}{h}\right)\left(\frac{A}{g\mu_BH_{\mathrm{ex}}}\right). \tag{2}$$

For example, in the Mn^{++} ion, with $S=\frac{5}{2}$, $A=10^{-2}\,\mathrm{cm}^{-1}$, $I=\frac{5}{2}$, and $H_{\mathrm{ex}}/H_{\mathrm{int}}=1000$, the line width will be about 0.14 Mc/sec.

Formula (2) is very similar [aside from the factor $(H_{\mathrm{ex}}/H_{\mathrm{int}})^{\frac{1}{4}}$] to the result of Moriya[7] applicable in the paramagnetic regime. Thus, the hope that ferromagnetic ordering of electron spins might make observation of nuclear resonance easier than it is in the disordered state does not appear to be justified.

The same process also occurs in antiferromagnetic materials such as MnF_2 and affects the resonance of the nuclei of both the magnetic and nonmagnetic ions. The result is much the same as (2) with the anisotropy field replacing H_{int}. This, and related topics, will be discussed in a forthcoming paper.

The author wishes to thank Dr. V. Jaccarino, Dr. A. M. Clogston, and Dr. P. W. Anderson for very helpful discussions.

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Possible Method for Determining the Intrinsic Parity of the K Meson*†

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AS a consequence of the nonconservation of parity in the weak interactions, including decays not involving the emission of neutrinos, there is no possibility of determining the intrinsic parity of a K meson or hyperon by observations on its decay.[1] However, there is no evidence of parity nonconservation in the strong interactions leading to the production of hyperons ($Y=\Lambda$ or Σ) and K mesons. Accordingly, it is of interest to consider possible means of utilizing some special features of the production processes for the determination of the parities of the strange particles.

It is to be noted that, since the "strangeness" selection rule requires the associated production of a hyperon and a K meson, such processes can only yield the intrinsic parity of the (Y-K) system produced. However, for simplicity, we shall in the following *define* the intrinsic parity of the hyperons to be identical with that of the nucleons. Thus, when we refer to a scalar K meson, it is to be understood to mean that the Y-K system has the same parity as the nucleons.[2]

A number of theoretical arguments have been advanced,[3] which tend to favor one parity or another for the K meson. However, in the absence of a complete theory of the strange particles and their interactions, such arguments cannot be taken as more than suggestions. An experiment proposed by Dalitz,[4] on the selection rules in the capture of K mesons by He^4, is one possibility for determining the K-Y parity. It is the purpose of this note to suggest another experimental approach to this problem.

We consider the associated production of a hyperon and a K meson by the collision of two identical nucleons,

$$N+N\rightarrow N+Y+K, \tag{1}$$

at bombarding energies sufficiently close to threshold to assure appreciable production of K mesons in s and p states only. Under these conditions, the resulting N-Y system is most likely to be in a relative S state. For those states in which there are strongly attractive forces between the hyperon and the nucleon, such as the forces leading to hyperfragment formation, the relative momentum between the resulting Y and N will be small compared to their total momentum (i.e., they will tend to come off together) and reaction (1) will resemble a two-body reaction. Such an effect has been observed, for example, in the case of radiative π^- capture by deuterium,[5] in which the resulting di-neutron, although unbound, exhibits a strong tendency to be emitted as a unit.

Table I summarizes the properties of reaction (1) near threshold, assuming such a "bound" final N-Y state, for the various possibilities concerning the angular momentum of this state and the K-meson parity. In preparing Table I, we have assumed a spin-0 K and spin-$\frac{1}{2}$ Y.

Another feature of the cross sections described by the last column of Table I is their energy dependence: The terms (amplitude squared) corresponding to $l_K=0$ vary, near threshold, as the K-meson momentum; the $l_K=1$ terms vary as the cube of the K-meson momentum.

There are indications, based on an analysis of hyperfragments[4] and on theoretical considerations,[6] that the Y-nucleon force is strongest in the $^1S_0$ state, possibly sufficiently strong to lead to a bound Σ-nucleon system. If such is the case, we may expect, for a certain fraction of reaction (1), a true two-body reaction, in which the K meson has a fixed center-of-mass energy, irrespective of its angle of production. For such reactions, especially, the predictions of Table I provide a means of distinguishing, through the energy dependence and angular distribution of the reactions, between a scalar and pseudoscalar K meson. Thus, for a scalar K, the angular distribution should be separable into an isotropic and a $\sin^2\theta$ term, the former increasing as the momentum of the K, and the latter as its cube. For a pseudoscalar K, the $\sin^2\theta$ term should be missing.[7] By taking advantage of these features, careful observations on these reactions may permit a determination of the K-meson parity.

TABLE I. Angular distribution of K mesons produced in $N+N\rightarrow(N+Y)+K$.

$Y-K$ parity	Final (NY) state	l_K	Initial (NN) state	Angular distribution
+	$^1S_0$	0	$^1S_0(a_0)$	$\lvert a_0\rvert^2$
		1	$^3P_1(a_1)$	$(9/2)\lvert a_1\rvert^2\sin^2\theta$
	$^3S_1$	0	Forbidden	
		1	$^3P_{0,1,2}(a_{0,1,2}')$	$\{(9/4)\lvert a_2'-a_1'\rvert^2+\lvert a_2'-a_0'\rvert^2\}\sin^2\theta$ $+\{(9/2)\lvert a_2'+a_1'\rvert^2+\lvert 2a_2'+a_0'\rvert^2\}\cos^2\theta$
−	$^1S_0$	0	$^3P_0(b_0)$	$\lvert b_0\rvert^2$
		1	Forbidden	
	$^3S_1$	0	$^3P_1(b_1')$	$\lvert b_1'\rvert^2$
		1	$^1S_0(b_0'),\ ^1D_2(b_2')$	$(1/3)\lvert b_0'-(5/2)^{\frac{1}{2}}b_2'\rvert^2$ $+\{\lvert b_0'+(5/2)^{\frac{1}{2}}b_2'\rvert^2-\lvert b_0'\rvert^2\}\cos^2\theta$

The presence of one of the authors (G. C.) at the Massachusetts Institute of Technology was made possible through the receipt of a Fulbright Travel Grant from the U. S. Department of State.

* This work was supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

† Some of these considerations were communicated at the Padua-Venice Conference on Mesons and Recently Discovered Particles, September 23–29, 1957 (unpublished).

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[2] This argument does not hold for the cascade hyperon, Ξ, since it is produced together with two K mesons. Furthermore, it is not excluded that the hyperons Λ and Σ may have opposite intrinsic parity. If this were the case, observations would yield opposite parities for the systems $\Lambda-K$ and $\Sigma-K$.

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[7] In both cases, a term proportional to the K-meson momentum cubed can arise from interference between s- and d-wave production. Such terms have a $(3\cos^2\theta-1)$ angular dependence, however, and should be distinguishable from a pure $\sin^2\theta$ term.